It is fair to say development rates in the shaft sinking industry have been heading south for some time.

An increased emphasis on safety, deeper lying orebodies and increasingly challenging underground conditions have slowed down shaft sinking rates, adding to the list of issues developers face when trying to finance new underground mines.

Mining engineers and shaft sinkers, alike, recollect when they could sink 100 m/mth and get to the bottom of ventilation or services shafts that much quicker, but, today, average rates are more like 40-50 m/mth, with anything above a bonus.

While productivity may have been that much more impressive four decades ago, safety was not.

Murray Macnab, Managing Director of Mets International, puts it into perspective.

“The way they sunk shafts in the past was productivity and production at all costs and it took many, many lives; effectively one life for every 100 m of shaft sinking,” he told IM.

“Today, we sink 1,500-2,000 m shafts without a single loss time injury.”

Take Glencore’s Nickel Rim South project in Ontario, Canada. The sinking of two concrete lined shafts simultaneously by Cementation – a 6.1 m diameter ventilation shaft to a depth of 1,680 m and a 7.6 m diameter main access shaft to 1,733.5 m depth – occurred without a lost-time accident.

Redpath’s General Manager of Shaft Projects, Kevin Melong, thinks the industry should be highlighting these advances as opposed to dwelling on past sinking rates.

“The shaft sinking fraternity can pride itself on the changed environments in which we undertake one of the most challenging aspects of the mining industry today,” he told IM.

These safety improvements are laudable, yet they do not lead to the advance in development rates the industry requires to ensure capex-intensive underground projects can be greenlit and, then, turn a profit.

This issue is only heightened by the fact more
open-pit mines will have to transition underground in future years to continue operations, and a greater number of recent discoveries are coming under barren cover that, should they become deposits, will require vertical development.

One would assume shaft sinking rates are going to have to speed up in order for future mines to come on stream.

**Acceleration**

Those manufacturing shaft sinking equipment and the contractors carrying out this specialised work are doing something about this.

**Cementation Canada**, after successful use at Shaft 10 at the Resolution copper project in Utah, US, is looking to include shotcrete as a temporary support measure in its own shaft sinking cycle.

The challenging conditions (temperature, water ingress, etc) experienced sinking the 2,116.2 m deep shaft saw the company remotely apply fibre reinforced shotcrete as a temporary support measure.

"With shotcrete, we remove people from the face. Instead of a miner with a handheld drill carrying out support work in the shaft wall, now we have a remote operator shotcreting," Roy Slack, President of Cementation Canada, told *IM*.

This brings obvious safety benefits, while speeding up the whole development process.

And, the company has also gone beyond what was traditionally thought of as the 'limit' for raiseboring within shaft sinking.

It used a large diameter raisebore to help sink a more than 5 m diameter shaft down to 1,500 m at Alamos Gold’s Young-Davidson mine in northern Ontario, Canada.

Redpath, meanwhile, is looking to redesign its conventional shaft sinking system to allow “safe concurrent tasks of the cycle to be carried out,” according to Melong.

"This requires innovative approaches to mucking and lining of the shafts, currently underway within our group,” he added.

These and other developments have Macnab thinking contractors and engineers can get a 10-20% improvement on the current monthly development rates with conventional drill and blast technology.

"I don’t believe 40-50 m/mth is going to be where it is forever," he said.

One company that has exceeded such rates is **Aveng Mining**, which is currently working on sinking Shaft 1 at the Platreef underground project on the northern limb of South Africa’s Bushveld Complex.

This project, majority owned by Ivanhoe Mines, requires the sinking of two shafts for ventilation and hoisting with the first 7.25 m diameter shaft going down to 980 m depth. The second shaft, which will have a rock hoisting capacity of 6.4 Mt/y, will be a 10 m diameter, 1,104 m deep concrete-lined shaft.

Aveng, through its Aveng Shafts & Underground subsidiary, started sinking Shaft 1 in July 2016 and, on April 23, 2018, reached a depth of more than 750 m below surface, allowing construction of the first mine development access station.

In the 12 months to June, development metres at Shaft 1 averaged around 50 m/mth, Aveng Mining Senior Contracts Manager Patric Scheepers told *Mining Review Africa* recently. March saw the company achieve 54 m/mth, which Scheepers said was a record.

These rates were achieved by moving to a continuous operations model with 340 permanent employees and an additional 50 subcontractors, Scheepers told the publication.

The company also transitioned from a conventional sinking approach to a two kibble-loading methodology which removed employees from the shaft bottom during mucking operations.

"This required careful engineering and change management at the time and was a major success," Scheepers said.

But, even so, Aveng would not even be carrying out such work if the
Platreef orebody was not of exceptional quality and width. While most in the platinum group metal space are closing shafts in response to stubbornly weak commodity prices, Ivanhoe is planning to bring Platreef online in 2022. This is because it has reserves of 125 Mt at 4.4 g/t 3 PGE+Au, an initial mining rate of 4 Mt/y and average annual production of 476,000 oz of platinum, palladium, rhodium and gold along with significant copper and nickel by-products. The asset also has a thick, flat-lying orebody that averages 19 m in width meaning it can be mined by mechanised means and could become Africa’s lowest 3PGE + Au producer when it starts up.

Without these characteristics, the $1.5 billion development simply would not be able to turn a profit today. There are fewer and fewer of these Tier-One deposits being found not only in the PGM space, but across the whole industry. That is why the magnifying glass has been held up to the shaft sinking sector to see if development rates can be sped up to allow more deposits – without such world-class features and cash-rich backers – to pass today’s investment return thresholds.

While the debate about mechanised shaft sinking goes on, conventional drill and blast projects continue worldwide. In July, Barrick Gold confirmed contractor Thyssen Mining had mobilised to its Turquoise Ridge site in Nevada, US, to carry out work on the sinking of a third shaft at the operation. The development, with additional processing capacity, is expected to roughly double annual production to more than 500,000 oz/y.

The project consists of sinking and equipping a 24-ft (7.3-m) diameter, concrete-lined shaft to 3,250 ft (991 m) depth, according to a technical report filed earlier this year. Shaft sinking will include two skipping levels, a water pressure break level, and a shaft bottom pump level, while equipping includes a headframe and collar house; hoists and hoistroom; shaft steel; surface and underground material handling; and a shaft bottom pumping system.

Cementation Canada, in partnership with Murray & Roberts, is busy sinking two shafts, each 7 m in diameter, down to 1,080 m depth at the De Beers’ majority-owned Venetia diamond mine in South Africa.

In North America, Cementation Canada is also carrying out work on Glencore’s Onaping Depth nickel-copper project in the Sudbury Basin of Canada. According to a March 2 report in Northern Ontario Business, the project includes the construction of a winze from the 1,200 m level laterally off the workings of Craig mine to access some 14 Mt of ore, 2,500 m from surface. The first 700 m of the winze will be raisebored down to the 1,900 m level and then slashed and extended beyond that to the 2,650 m level using conventional shaft sinking technology.

Redpath’s Melong said the company was winding down operations at two Canada potash shaft sinking contracts with “composite liners, underground freeze conditions and the rehabilitation and upgrade/reconfiguration of an existing shaft hoisting system”, while, in Europe, the company is completing two other conventional shaft sinking projects.

In Mongolia, the GCR Mongolia joint venture won more work at Oyu Tolgoi earlier this month, with the three partners (Gobi Infrastructure Partners, Clough Projects International and RUC Cementation Mining) set to design, construct and commission the sinking and lining of Shaft #3 and #4.

This involves blind sinking and concrete lining of the two 10-11 m diameter shafts down to depths of some 1,150 m for ventilation. Lastly in contracting, earlier this month Jastrzebska Spółka Węglowa, one of Europe’s largest coking coal miners, signed an agreement to purchase a 95% stake in shaft sinking specialist Przedsiębiorstwo Budowy Szybow (PBS) from the Kopex Group.

The PLN 205.3 million ($55.6 million) agreement came as a result of FAMUR SA’s acquisition of Kopex, completed earlier this year. PBS has carried out more than 132,300 m of shaft sinking, including 35,000 m in hard coal mines and 67,000 m in ore mines.

Cementation Canada’s recent shaft sinking work has focused on removing people from the shaft bottom, while using innovative methods to speed up sinking rates.

DMC Mining Services CEO Graham Buttenshaw thinks the industry needs to look at the fundamental drill and blast technology it is using to sink shafts in order to improve metres per month.

“Shaft sinking has not changed much since the 19th century. You still get a bunch of guys that go down in large yellow rubber suits, drill holes, fill them with explosives, light the blue touch paper and retire and then wait for the bang before digging it out. It is ancient technology,” he told IM.

Ivanhoe Mines plans to sink two shafts as part of its Platreef PGM project in the Bushveld Complex of South Africa.

But, Cementation Canada’s Slack thinks the industry needs to examine the bigger picture, not just shaft sinking rates, in order to achieve the required project delivery rates.

“There is more to this than just measuring how many m/d you can sink at. When we look at the total project, actual shaft sinking represents the asset’s overall achievement.”
only about 25% of the schedule, so trying to increase the development rate by a metre or two a day has very little impact on the overall schedule," he told IM.

"If you look at the time to do prefeasibility, detailed engineering, surface setup, the actual sinking of the shaft, development of the stations, installation of the loading pockets, the commissioning of the whole plant, etc, the shaft sinking is a relatively small part of the total project."

Macnab thinks lateral development rates should be factored into the discussion.

"If you have a look at the overall programme, the shaft has a high intensity capex schedule but is normally not the biggest part of the equation. The biggest part, which people often forget, is the development to open up the mine," he said.

This is where mechanised lateral development technology is accelerating payback with innovations like Master Drilling's Mobile Tunnel Boring solutions and Epiroc's Mobile Miners.

"Mechanical excavation

Such innovative technologies in the vertical mechanised development space require "large sums of money and equally committed mine owners' teams and the traditionally impatient shaft miner," Melong said.

"The combination of these constraints and the inherent risks due to the criticality of the shaft sinking process to the economics of a mine, has limited the development and application of these new models."

Deilmann-Haniel has developed one such technology, through Thyssen Schactbau, with Herrenknecht and Murray & Roberts Cementation.

The Shaft Boring Enlarger (SBE) uses V-Mole technology established by Wirth many decades ago and acts like a vertically-oriented modern hard-rock tunnel boring machine (TBM).

The sinking of a shaft with the SBE occurs in three phases: pilot hole, enlargement to pilot borehole diameter with a reamer and enlargement to final diameter of 7.5-9.5 m with the SBE.

With the help of laterally extendable hydraulic cylinders, the 15 m high and 350 t machine "braces itself before every drilling stroke in the shaft, steadying the machine, allowing the thrust cylinders to push the rotating cutterhead against the borehole floor," Herrenknecht said.

A laser aiming device ensures precise vertical alignment, while the rotating anchor platform, where anchors and steel mesh can be put in place by two hydraulic drill rigs, is situated on the drilling deck above the cutterhead.

If required, a shotcrete unit on the machine secures the shaft wall immediately after exposure of the rock outcrop.

SBE technology reduces shaft sinking time by 20-30% compared with conventional shaft sinking technology, according to Herrenknecht.

Jochen Greinacher, Managing Director of Deilmann-Haniel, said: "It is a good working system for the right applications. We sank shafts with that technology of up to 50 m per day at its peak in a coal mine in southern Germany (Pirmasulle shaft, at Endsdorf colliery)."

The average rate of 7-7.5 m/d compares favourably with the circa 1.5-3 m/d conventional drill and blast typically achieves and the machine operator controls the SBE from the interior of the machine providing further safety advantages.

Drillcon is another contractor that has shown big interest in our Epiroc Easer rig and we will perform a test trial with them later this year in Portugal. Lundin Gold has recently purchased an Epiroc Easer rig for their operation (Fruta del Norte) in Equador. Other mining customers that have shown interest are LKAB in Sweden, Barrick in Canada, Kola MMC Russia and Ferbasa Brazil.

We recently ran a test trial with Ferbasa in Brazil where they wanted to see how the Easer method would measure against the ITH slot hammer method they used. They have looked into performing slot raises with a raiseboring machine previously, but the long setup time and slow relocation ruled that out. That's where the Easer came in with its flexibility, fast and easy setup and, in addition, its fast relocation. Using boxhole and down reaming methods, deviation was less than 1%, on average, and the penetration rate was 2.47 m/h. All in all, they were able to reduce the total time for a slot raise by 60% with the Epiroc Easer versus ITH slot hammer.

Q I understand the Eaiser has been used in three different drilling modes recently by Pybar at the Hera mine (boxhole, down reaming and conventional) in Australia. Where are you seeing most market demand/use for the Eaiser?

A For a contractor, I would say the demand/use of the Epiroc Easer rig would be split equally between the three modes since they most likely will be doing everything from slot raises to holes for utilities. For mining customers, it will follow the type of production drilling method they are using, so the Epiroc Easer rig would mostly be used for boxhole and down reaming.

Q How does the Eaiser fit into Epiroc's wider raiseboring offering? Is there need for further mobile raiseboring models to meet customer demands?

A The Epiroc Easer rig has been a really good complement to both our Epiroc raiseboring products and production drilling equipment (replacing slot raising with ITH). We have seen a demand for a lower profile model that better fits the smaller drift sizes in the medium size segment (4 x 4 m – 4.5 x 4.5 m).

Q Apart from Pybar, what other companies have shown an interest in using the Eaiser?

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"But, don’t forget, mucking is not part of the cycle," Greinacher told *IM*. The SBE cuts the rock as the shaft liner is installed, but there is no capacity for a concurrent mucking cycle. This means an access drift, as well as equipment, is required at the lowest part of the shaft to transport the muck to surface.

Such limitations have reduced widespread adoption, but there is another technology that the developers claim it can carry out cutting, shaft lining and mucking concurrently.

German company Herrenknecht’s Shaft Boring Roadheader (SBR) technology has turned mechanised cutting technology on its head.

The SBR, developed as part of Herrenknecht’s involvement with Rio Tinto’s ‘Mine of the Future’ programme in 2013, is designed for the mechanised sinking of blind shafts in soft to medium-hard rock. It is an adaptation of the Vertical Shaft Sinking Machine the company uses in tunnelling.

The machine is suspended from ropes and connected to winches on the surface. It uses a roadheader boom, controlled remotely from work decks above, and a rotating cutting drum with 600 kW rated power to cut rock up to 120 MPa and create variable shaft diameters from 8-12 m.

In the first step of the cycle, the cutting drum creates a cut of up to 200 mm depth with more circular sections cut clockwise from the shaft centre to the shaft wall. After five cycles, the shaft cross-section is one metre deeper. The SBR is further lowered and the cutting cycle begins again.

The real innovation comes with the pneumatic mucking system to suck up loosened rock from the shaft bottom and transfer it to kibbles 20 m above the working level. It also has the ability to install shotcrete as ground support from an upper working deck – all while cutting is going on below.

This provides increased safety benefits – removing workers from the face – while transitioning shaft sinking to a continuous as opposed to batch (stop-start) process.

As with any new technology, the mining industry will be looking for successful references before incorporating the SBR into development plans.

**Case studies and projects**

*IM* understands three SBRs have so far been manufactured, with the first two ‘generation one’ units sinking two 1,000 m shafts with 8-11 m diameters through soft-medium strength rock in Saskatchewan, Canada at BHP’s Jansen potash mine.

DMC is carrying out the work, advised by Herrenknecht, and said the shaft sinking, which involved freezing rock down to 710 m and lining, is almost complete.

The third and fourth SBRs – the second generation – are destined for Slavkaliy’s Nezhinskiy project in Belarus; a project to sink two shafts down to 750 m depths, with freezing required to 160 m depth, according to contractor Deilmann-Haniel.

Nezhinskiy is expected to have an annual capacity of around 1.1-1.2 Mt/y of potash.

Deilmann-Haniel signed the more than €200 million contract back in July 2017, with the company set to start SBR sinking work in January 2019, according to Greinacher.

He said improvements have been made to the SBR’s pneumatic mucking system, in particular, as part of the design for the latest machines. This should see the company able to achieve a development rate of some 3 m/d, close to double
what it benchmarked with conventional drill and blast.

The only other confirmed SBR order from the mining sector is for Sirius Minerals’ potash project in the northeast of England (see more details in the DMC Mining Q&A).

The company is attempting to build a 10 Mt/y polyhalite mine that makes use of a mineral transport system, located in a 37-km long and 4.3 m wide tunnel at an average depth of 250 m below ground.

**Harder rock applications**

All SBR applications to date have been in soft-medium rock. Hard rock applications are likely to prove that much trickier and require, either, a more robust cutting head design and bits or an element able to induce rock fracturing.

Herrenknecht has also developed the Shaft Boring Machine (SBM) as part of Rio’s Mine of the Future programme, which can create blind shafts with diameters of up to 12 m in >120 MPa rock down to depths of 2,000 m.

The SBM raises excavated rock from the shaft bottom and transports it vertically through the machine via an innovative cutting wheel. In the first step, the cutting wheel penetrates the rock like a circular saw, creating a slit with a depth of 1.5 m. In the second step, it rotates around the vertical axis of the machine to cut out the entire shaft profile.

Herrenknecht said: “In doing so, the cutting wheel not only loosens the rock but also serves as a paddle wheel which transports the muck via integrated channels to the centre. There the material is transferred to a vertical belt conveyor, which transports it to the transfer point for shaft conveyance.”

Up to three gripper systems brace against the shaft wall and stabilise the entire system during this procedure.

As is the case with a hard rock TBM, shotcrete is introduced via remote control directly behind the cutting wheel. The disc cutters are replaced in a specially secured working area which is easily accessible and protected against falling rock. Thus, no personnel have to remain in dangerous areas during normal operation.

The company is also working on its Shaft Boring Cutterhead, a machine rated to cut >120 MPa rock down to 1,000 m depth with shaft diameters ranging from 7-12 m.

The conical cutterhead is equipped with disc cutters for hard rock applications. It is capable of delivering an advance rate of 6 m/d and uses a similar pneumatic mucking system as the SBM, according to Herrenknecht.

While it is still early days for these technologies – neither the SBM or SBC is currently in use on a project – the introduction of mechanised cutting has seen tunnelling and civil engineering contractors enter the shaft sinking market.

Greinacher said Deilmann-Haniel is involved in two projects where it is competing against civil engineering companies, while Slack said Cementation Canada, which celebrates its 20th anniversary this month, has recently seen tunnelling and civil contractors bidding for some large mining development projects.

The likelihood is these companies will have to sub-contract work to more experienced contractors in the mining space to ensure it meets industry standards.

Koos Jordaan, Master Drilling Executive Director told IM: “Master Sinkers, a subsidiary of Master Drilling will commence with a soft to hard rock shaft sinking experimental trial by method of rock boring during Q1 2019. The trial will involved the testing of a pilot shaft system that is part of a larger system to be used in either blind sinking or enlargement mode for large diameter and deep shafts predominantly used for mine access and ventilation. This service will compliment Master Drilling’s raise boring and mud flooded air lifted reverse circulation boring shaft infrastructure construction capabilities, as an advanced technology shaft solution provider.”

**No silver bullet**

Given the inherent variability of underground deposits, mechanical cutting is unlikely to be suitable for all underground developments.
Melong said: “The challenge has been to introduce change that can be applied across a broad spectrum of shaft project types to improve performance. This is the current challenge with mechanical excavation, as any given project presents a myriad of differing geotechnical or hydrogeological constraints that drives the methodology to be applied,” he said.

Greinacher agrees with this point: “In particular, where you have changing conditions – soft ground to stable ground, to water-bearing ground, etc – conventional drill and blast technology is way more flexible to adapt to these conditions.”

And, there is a tradeoff that has to be made, according to Macnab.

“No all projects are justified using it in terms of shaft depth...there is a cutoff point on these machines where it does not make economic sense.”

As it stands, mechanised shaft sinking projects will need a sizeable orebody at depth, the right rock strength and fracturability, and an owner willing to take some development risk. It will also require a different approach to project development, Slack said.

“If you look at the nature of feasibility studies, they talk about implementing proven technology. So, your feasibility will be based on proven technology and the new technology will be an opportunity. It will then involve selling it to the project review committee or board.”

MC Mining Services (KGHM Group) is one of the rare contractors to have used innovative SBR technology in mining. Currently working on sinking two 1,000 m deep shafts at a major potash project in Saskatchewan and preparing to use another generation of SBR at Sirius Minerals’ polyhalite project in the northeast of England, Dan Gleeson quizzed Graham Buttenshaw, CEO of DMC Mining Services, and John Luckock, Project Director for DMC Mining Services (UK) Ltd, about the technology.

Q. When Sirius Minerals announced the contract for its Woodsmith mine the company mentioned SBR technology could accelerate delivery of first polyhalite by up to six months. How are you able to do this?

JL The fundamental difference between a drill and blast development of a shaft and an SBR development is that a drill and blast process is sequential, with each task performed one after another.

The huge advantage the SBR brings, in addition to there being no explosives and an integral improvement in safety, is that cutting can work continuously and concurrently with other activities. Once the machine is in position, you can grind the material from the work face at the same time you are removing the material from the shaft area and sending it to surface. While that process is going on, you can also perform other tasks such as installing permanent liners to reinforce the shaft. It is this combination of activities that increases the productivity.

When we carried out the proposal for the Sirius contract, we baselined the project using drill and blast technology and then analysed the same project using an SBR. It was on this basis, we arrived at the ability to be six months ahead of the drill and blast schedule.

In addition to the two main shafts at Sirius going down to around 1,600 m depth, we are also developing two other shallower shafts for the lowering of TBMs underground.

Q. I understand you will be using a new generation of SBR for the Sirius project. How did your work on the major potash project in Saskatchewan influence the development of this latest machine?

JL We took a lot of lessons learned from the Saskatchewan potash project and using the first generation SBRs, and said to ourselves: ‘what can we do to further improve the process and accelerate the shaft sinking?’ It is those concepts that have been designed into the next generation.

There are a couple of fundamental changes. One of them is, on the Saskatchewan potash project, you could not perform concurrent lining operations with shaft sinking. You would sink, stop and then install the lining. The next generation SBR has a moveable or floating liner deck, which allows the lining to be installed at the same time as excavation.

We have also changed the conveyances between the working face and the surface, selecting a single bucket system to remove the spoils and a totally separate system that runs independently to bring personnel and materials up and down between the surface and work face. We have gone one step further to employ the use of a slick line for bringing concrete down for pouring the liners. All three are independent and work concurrently, so it eliminates the stop-start nature that we encountered previously.

Also, at Sirius, we will have a fibre optic connection from machine to surface. This allows us to run the machine from surface without having the operator down at the face. At this point, it is not fully remote – miners will be required to carry out certain functions on the SBR – but staffing is certainly reduced.

Q. How do the two projects – the Saskatchewan potash project and Sirius – compare in terms of geology and rock strength?

JL The geology at the project in the UK is largely sandstone, mudstone and anhydrites, so the structure of the material is not dissimilar to the material in Saskatchewan.

In terms of rock hardness – one of the key factors determining the advance rate – we found very similar properties to the Saskatchewan project, which enabled us to anticipate what our cutting rates would be for the UK project. There are, at Sirius, some areas where there is a slightly higher peak strength, but, in general, mean values are comparable.

Q. The general consensus is SBRs are used for shaft sinking with rock strengths ranging from 5 to 120 MPa and shaft diameters from 8-12 m. Is there potential for using the technology in applications outside of this?

JL There most definitely are. Saying that, the diameter becomes a limiting factor – too small and you restrict the working space; too big and you could potentially have problems with the force applied to the material. You would have a very long boom manipulating the cutter head and, the longer the arm is, the less force can be applied to the face. I don’t see, for example, this going out to 20 m diameter at this point in time.

GB In terms of rock strength, there is a hard-rock version on the drawing board, not dissimilar to a TBM with a vertical cutting wheel on it. We understand this version can potentially go well above 180 MPa.

But, it is not just hardness that is a key controller for the SBR’s cutting effectiveness – it is also the rock fracturability. There have been times at the Saskatchewan project where we have gone at a greater rate of cutting because the rock was inherently fractured and, therefore, the pick heads would bring out larger cuttings, increasing the development rate.

SBRs are where the future lies and that is why we, at DMC, are committed to using this technology wherever we go. We have been talking with companies in Chile, Thailand and Spain who are now showing serious interest in pursuing this. We need to make sure we apply this technology to not only soft and mid-hardness rock mines, but also hard-rock mines.